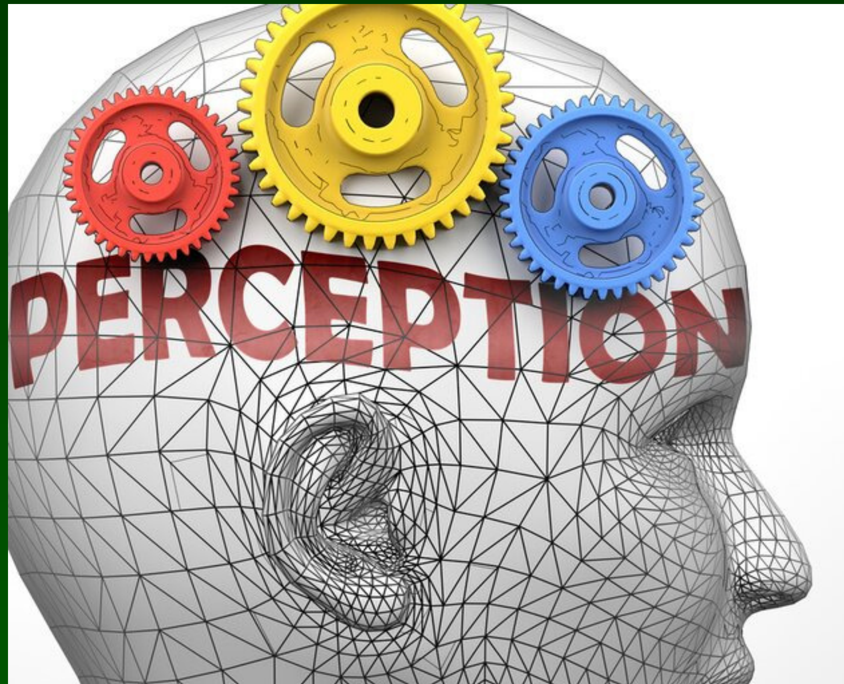
Selected topics in cognitive science and biomodeling

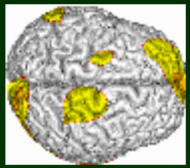


L8: Perception general + touch

Włodzisław Duch

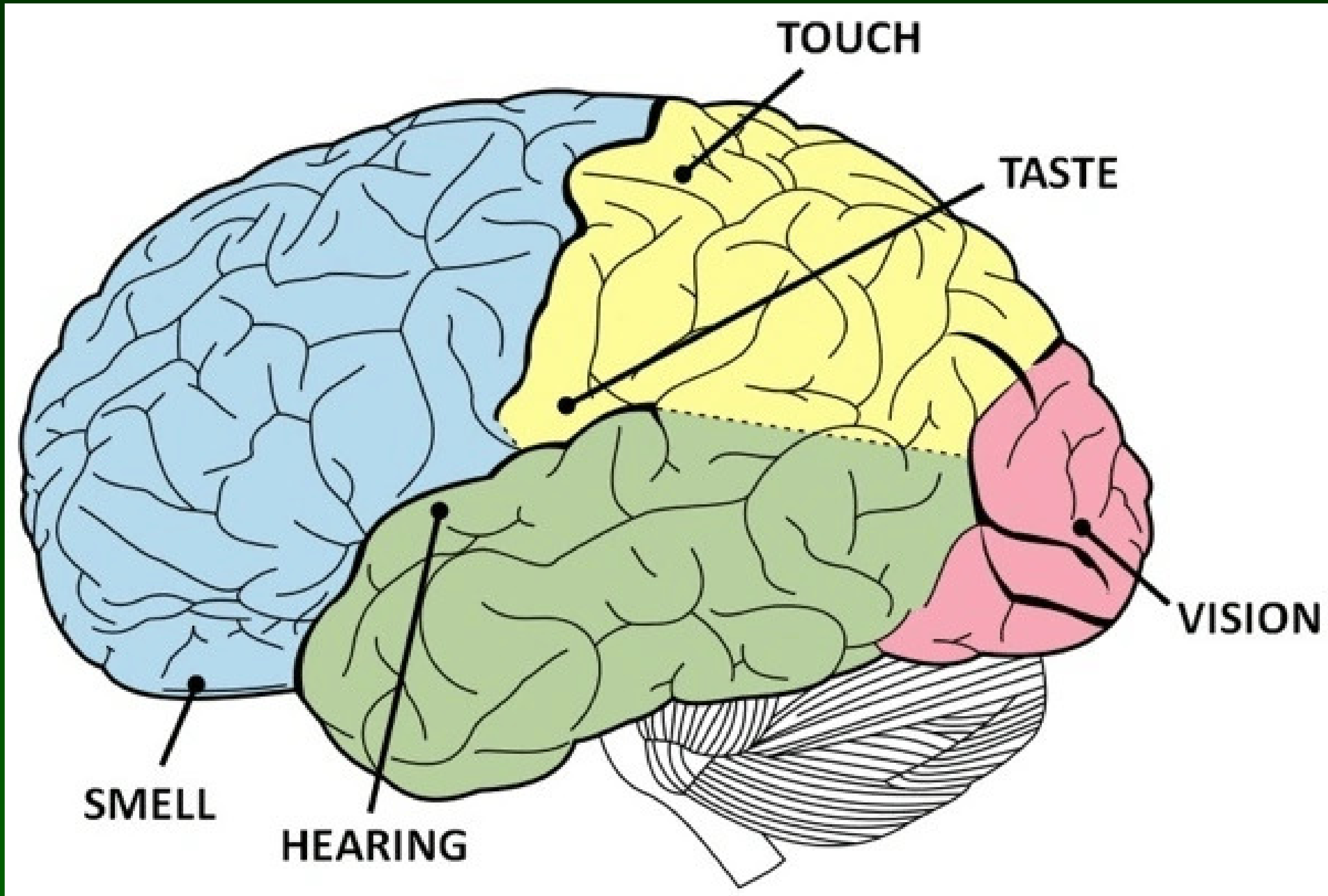
Neurocognitive Laboratory & Dept. of Informatics
Nicolaus Copernicus University, Poland
Google: Wlodek Duch

What it will be about



1. Information flow in the brain.
2. Sensory input coding - receptors.
3. Cortex functions.
4. Learning, coding sensory information.
5. Topographical maps and somatosensory perception.
6. Population coding – active perception.
7. Sound perception.
8. Vision.
9. Memory …

Sensory Inputs Coding

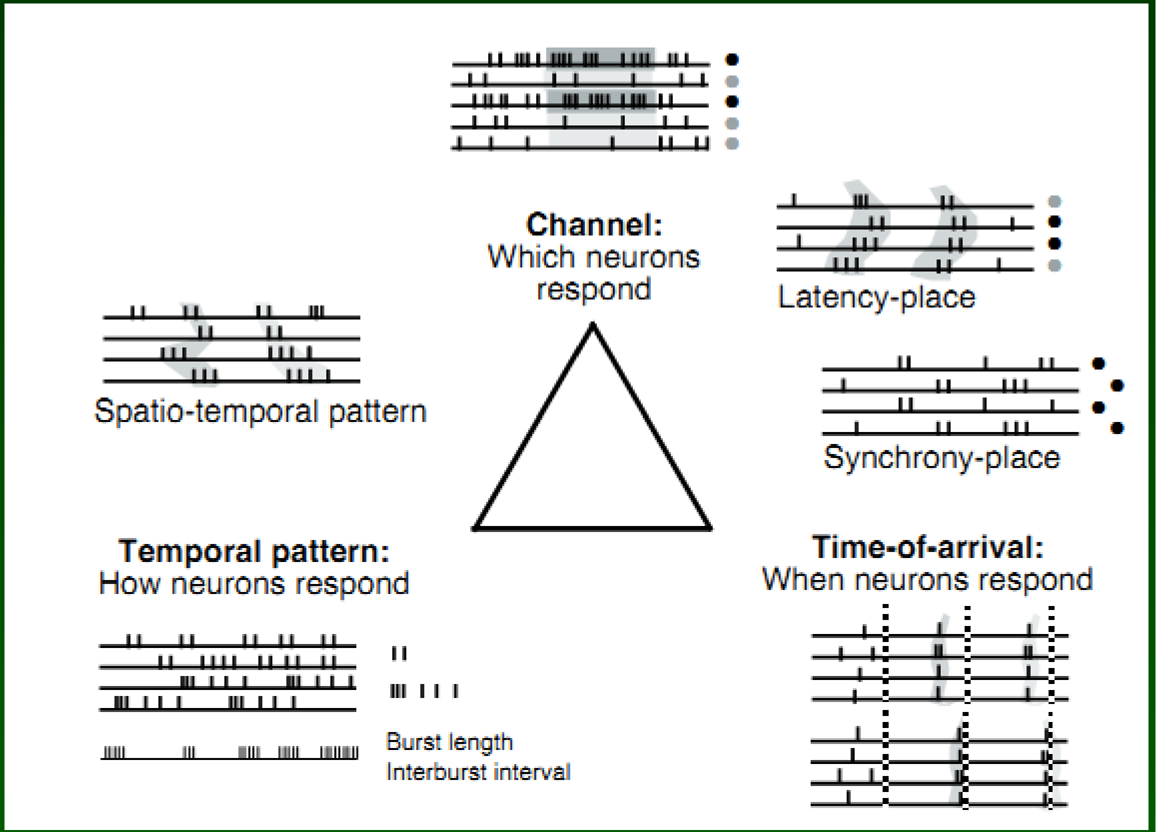


Perception => action! Visual, auditory, olfactory, tactile, smell => motor
How do we process and represent sensory information?

Brain information code

- All brain states are just spikes – how is information encoded in spikes?

1) channel-codes (spatial activation patterns),
2) temporal spike patterns
3) spike latency (relative spike timings);
4) rate coding.

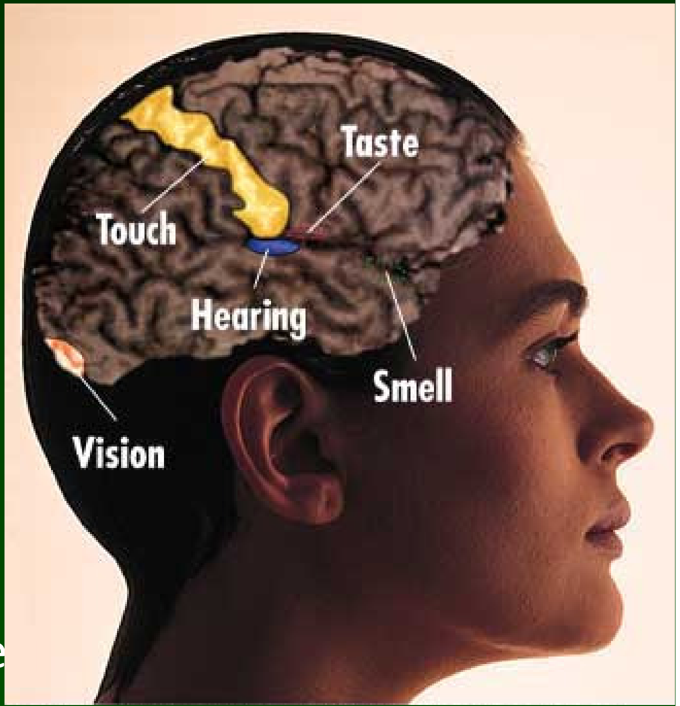


Stimulus-driven temporal correlations (phase-locking), are common in audition, vision, tactile perception.

Intrinsic temporal response structure in all sensory systems.

Particular temporal patterns of electrical stimulation elicit specific sensory experience (from Cariani, 2001); we shall used only rate coding.

Cortex functions



Cortex has three major functions:

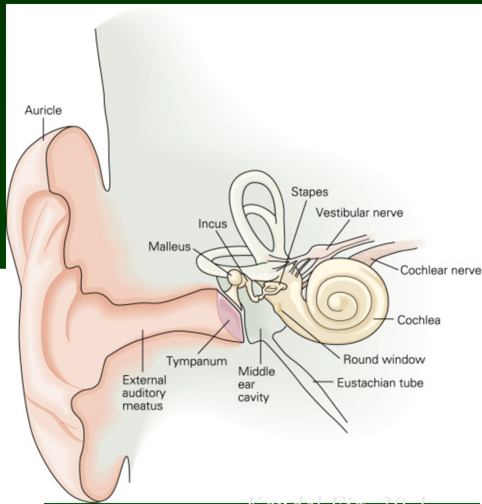
- precise analysis of sensory data;
- control of movements;
- complex cognition: association, planning, categorization of brain states (including reflection on the organism state).

All perception and action in the brain has to be coded by neural activity. Analysis is possible thanks to segregation of the data flow in thalamus and then cortex, and specific structure

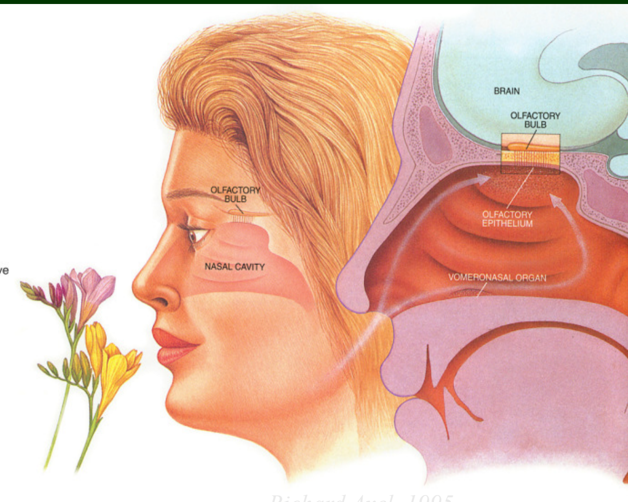
Primary sensory cortex: inputs from receptors => spinal nerve => thalamus, expects specific structure of information depending on modality.

Ex: somatosensory system reacts to touch (several mechanoreceptors and chemoreceptors), temperature, proprioception (internal body information), and nociception (pain), receiving it in BA 1-3, knowing where it comes from.

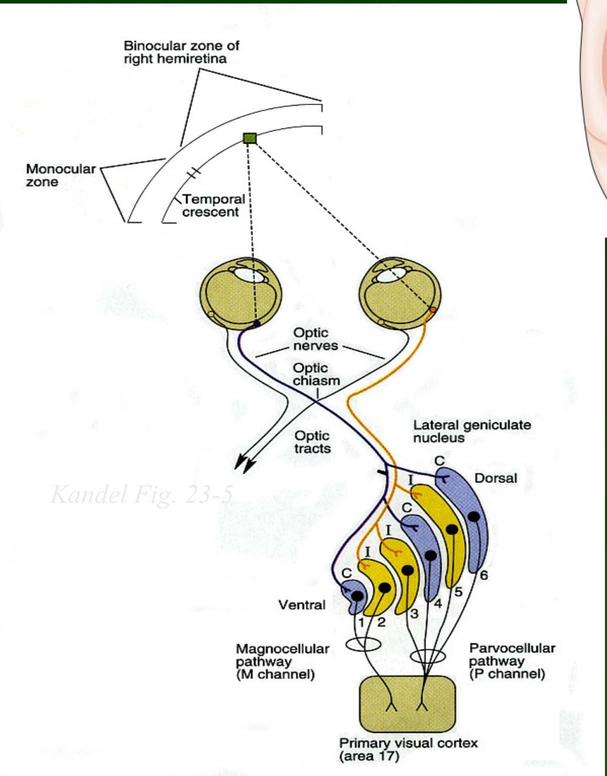
Sensory Inputs Coding



Kandel Fig. 30-1

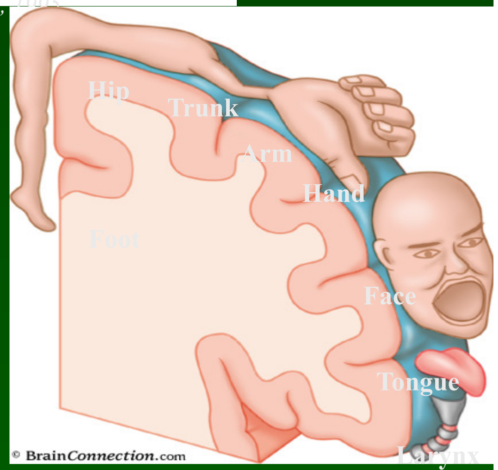


Richard Axel, 1995



Kandel Fig. 23-5

Visual, auditory, olfactory, tactile, smell => motor



How do we process and represent sensory information?

How many senses do we have?

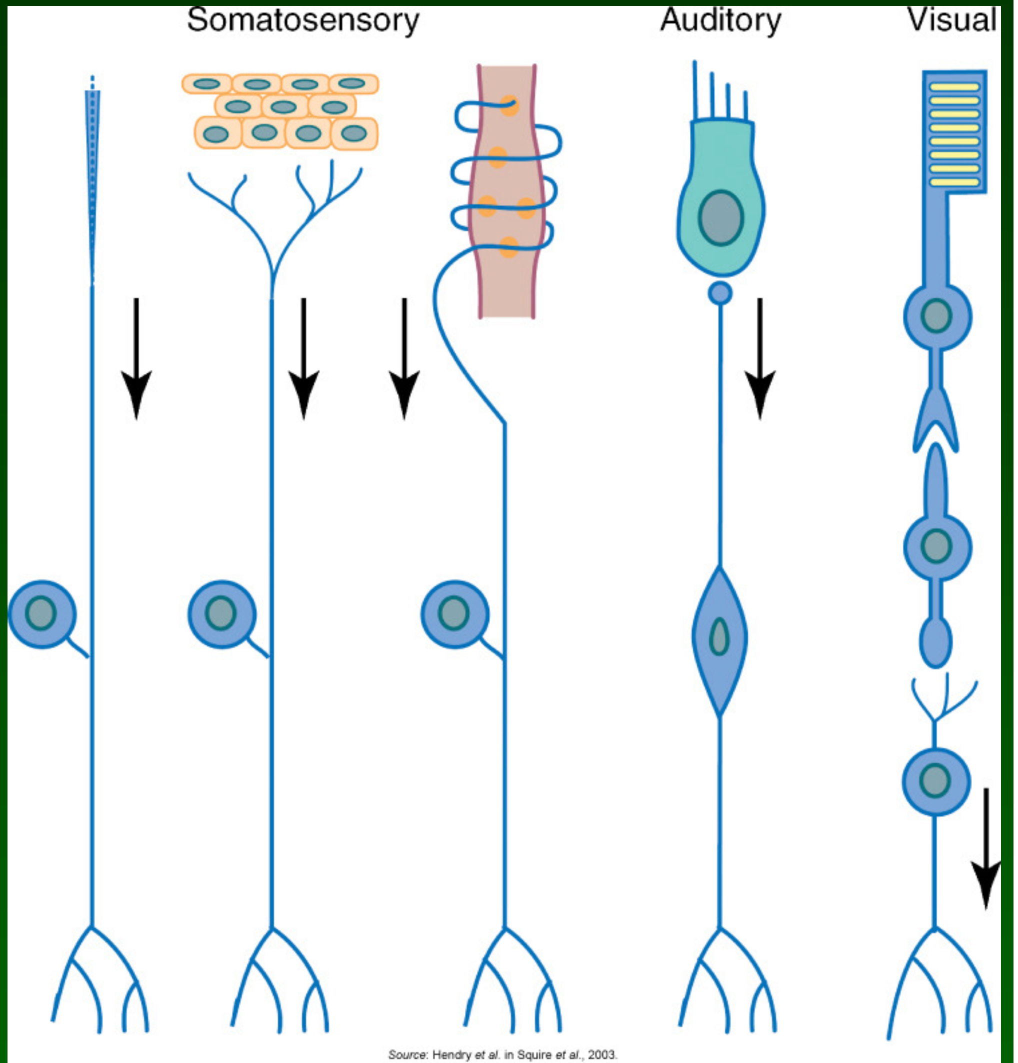
Different types of receptors

There are several types of receptors: mechanical, chemical, and photoreceptors.

However, they are all similar in structure and function.

Sensory nerves have parallel pathways sending sensory information to thalamus and sending back feedback information.

- 90% of brain regions have backwards projections towards the source.
- Most sensory and motor pathways split and cross over the midline of the body

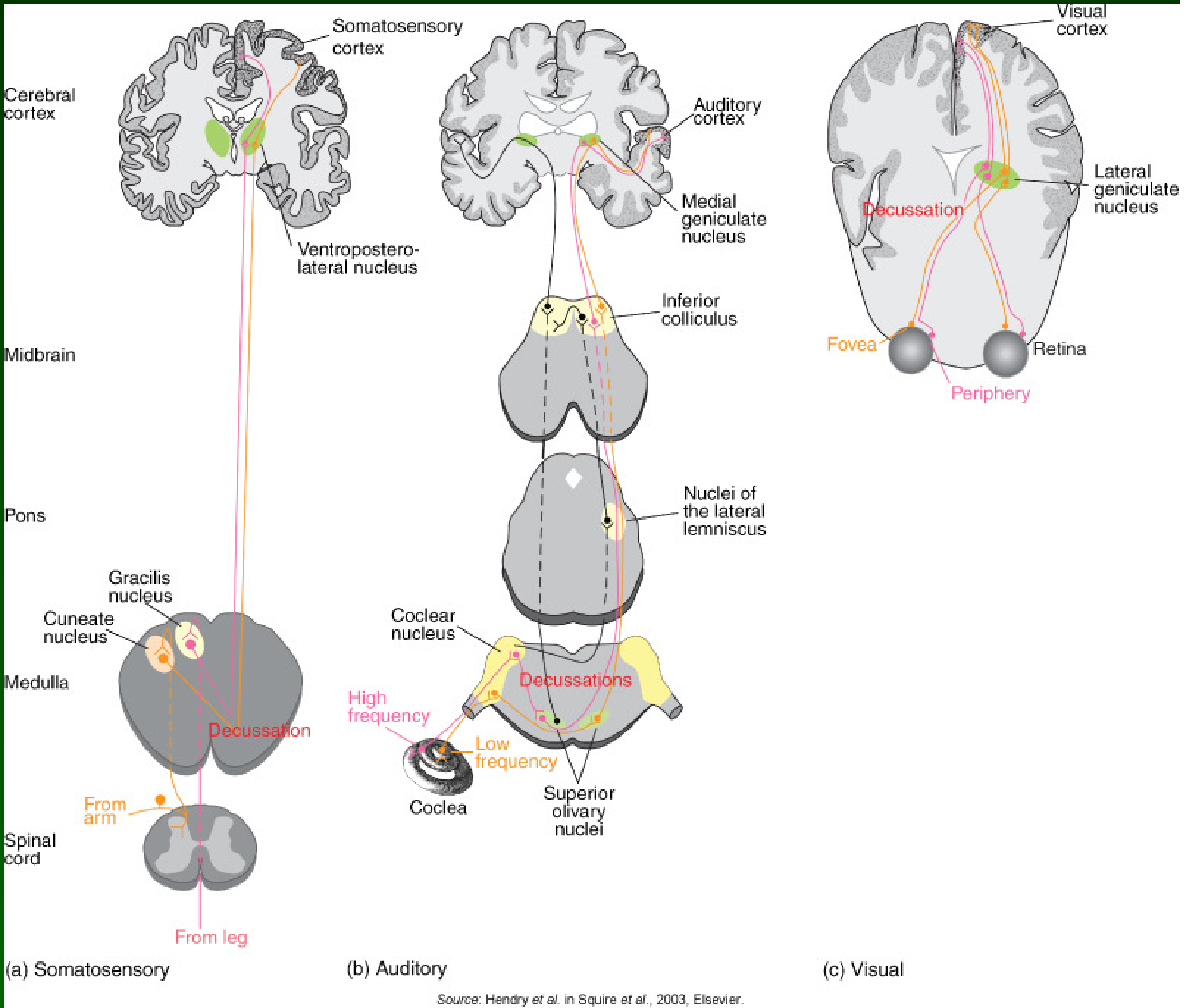


Similarities between sensor pathways

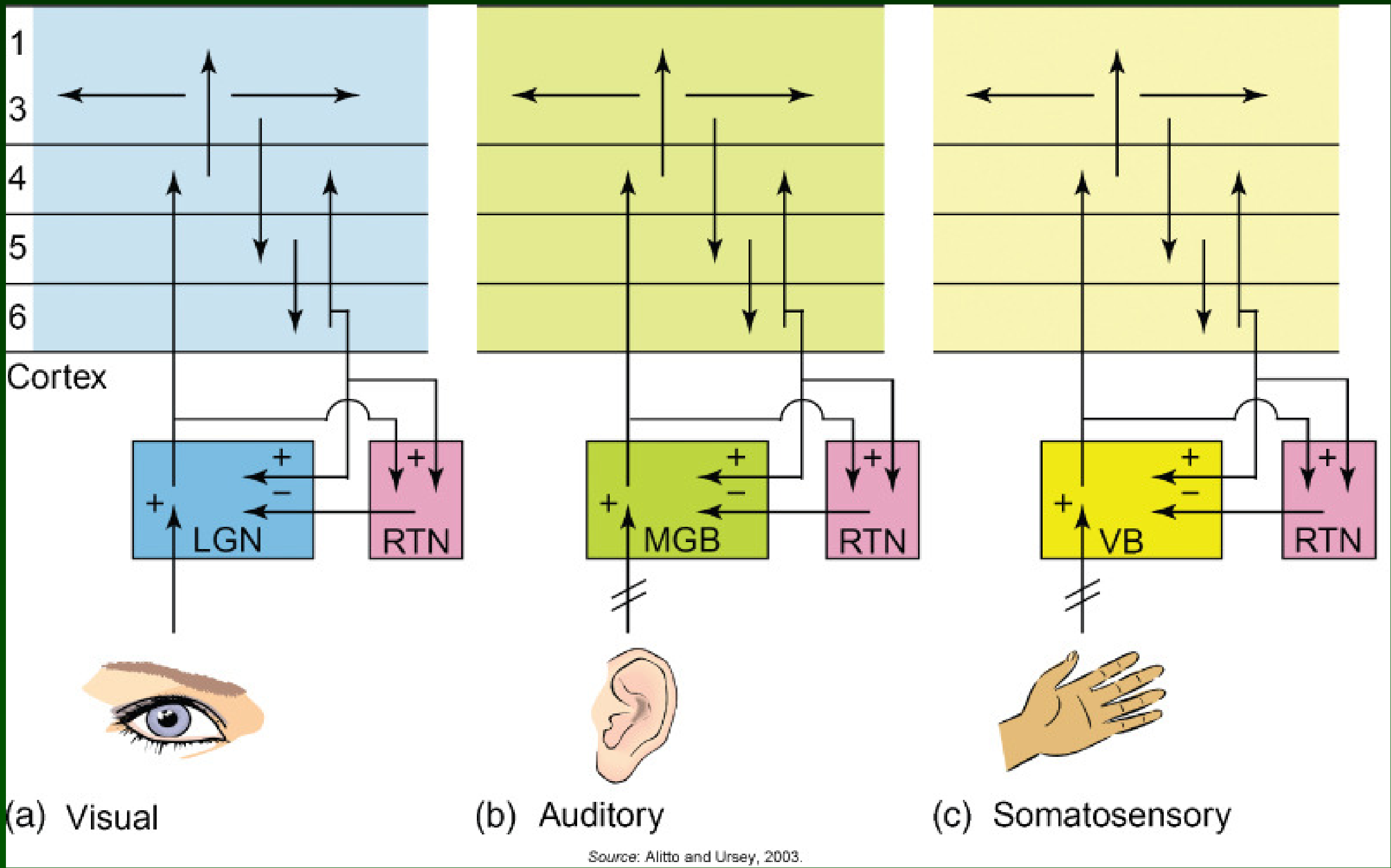
This image shows the similarities between the different sensory streams.

- arm vs. leg,
- high frequency sound vs. low frequency,
- foveal vs. peripheral vision.

Humans have about 250 000 fibers (axons) carrying signals from the skin to the brain.



Sensory Interactions



Sensory regions interact with thalamic nuclei (RTN)

Notice similarities between cortical input and output layers in all senses.

Sense of balance or equilibrioception is based on vestibular system, pressure of fluid in the semicircular canals in the inner ear.

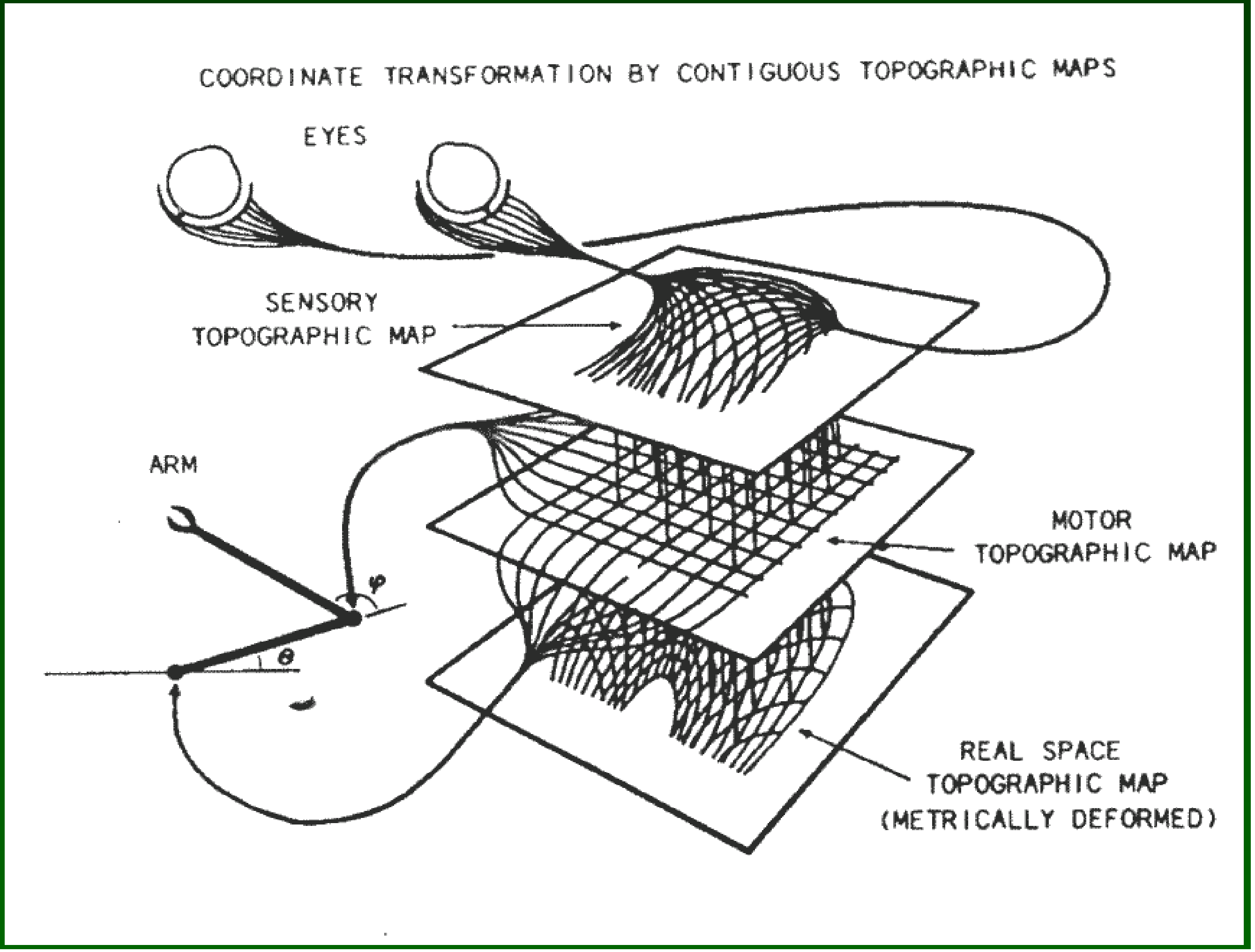
Sensorimotor maps

Converting percepts into actions requires complex transformations of sensory signals into specific motor activity.
Topographic maps reflect features of the environment.

Fig. from:

P.S. Churchland,
T.J. Sejnowski,

The computational brain. MIT Press, 1992



Topographical maps

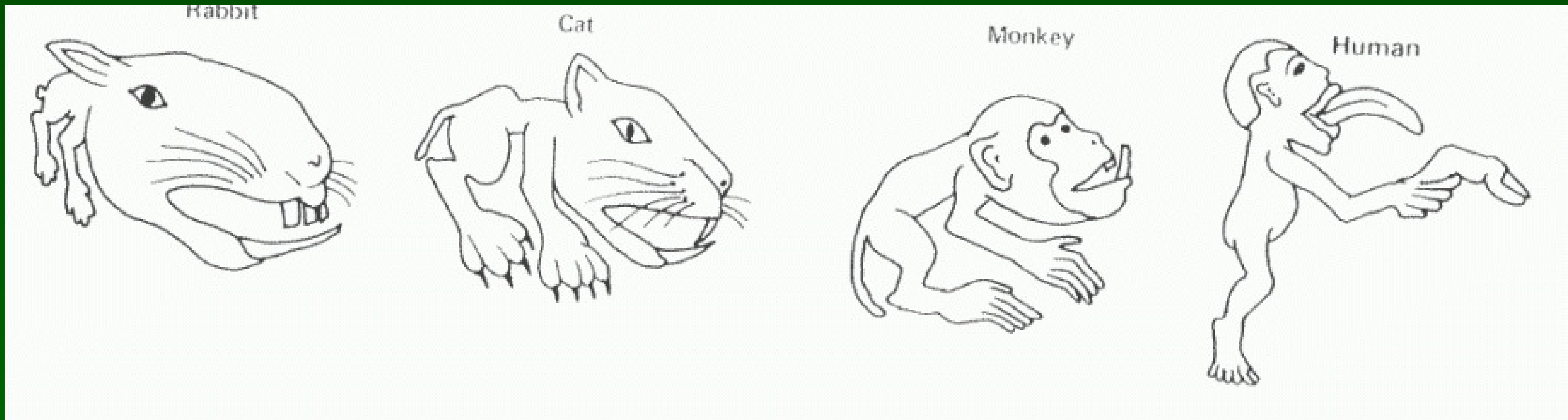
How can the brain determine where the stimuli occurred, which muscles to move or find how similar stimuli are?

By processing similar stimuli in adjacent areas, i.e. using topographical organization of sensory and motor maps.

More precision requires more computing power = more cortex area.

Rodents devote large part of their brain to analyze signals from their vibrisa and mouth, humans from hands and face.

Primary sensory cortex is topographical organized: auditory, retinotopic and superior colliculus, motor (MI and cerebellum maps), olfactory ….



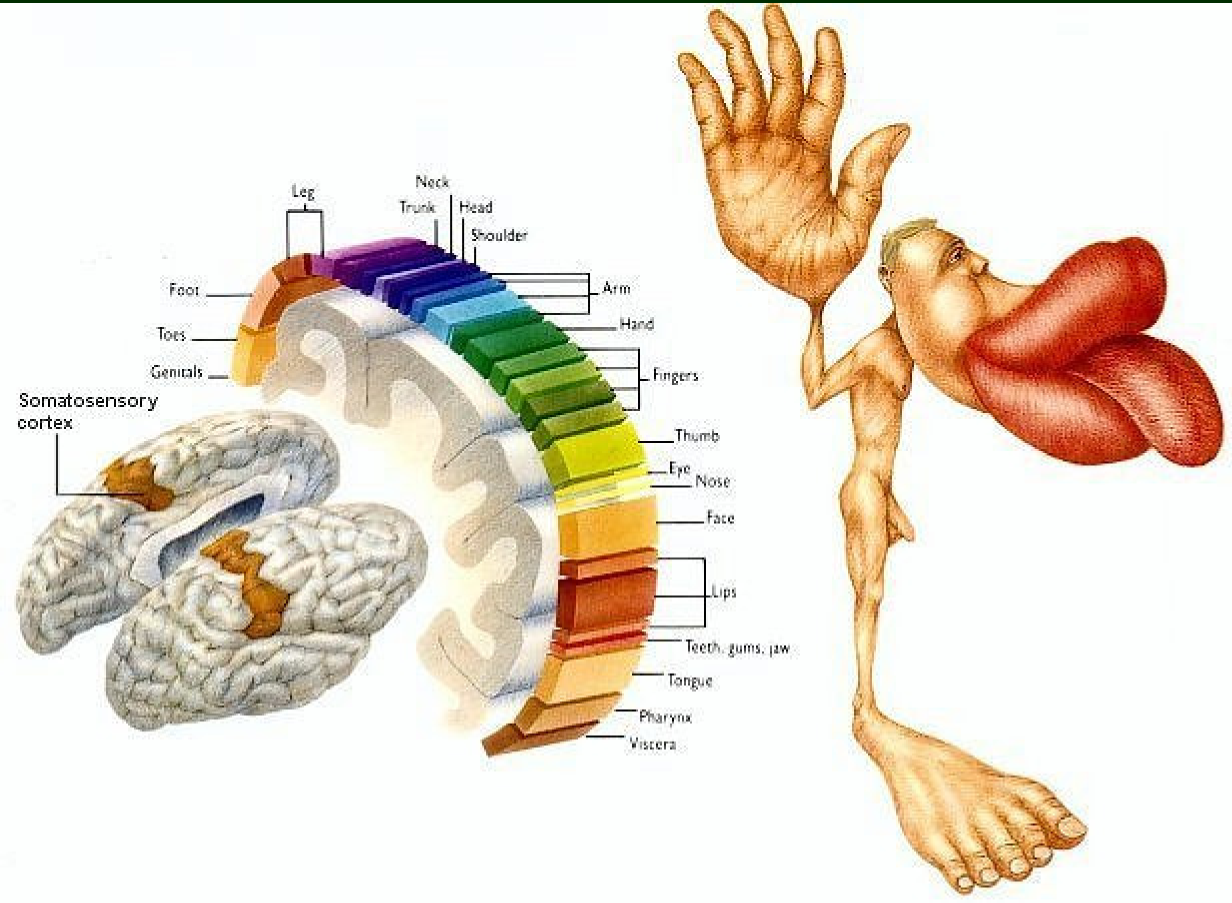
Topographical representations

Self-organization is modeled in many ways; simple models are helpful in explaining qualitative features of topographic maps.

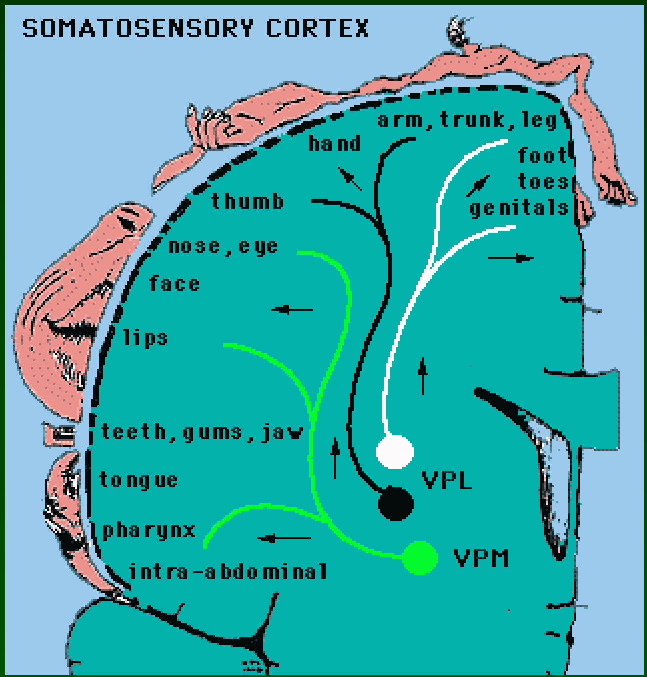
Many examples, best known are somatosensory and motor primary cortex, but many other motor and sensory areas have topographical organization, including visual and auditory areas.

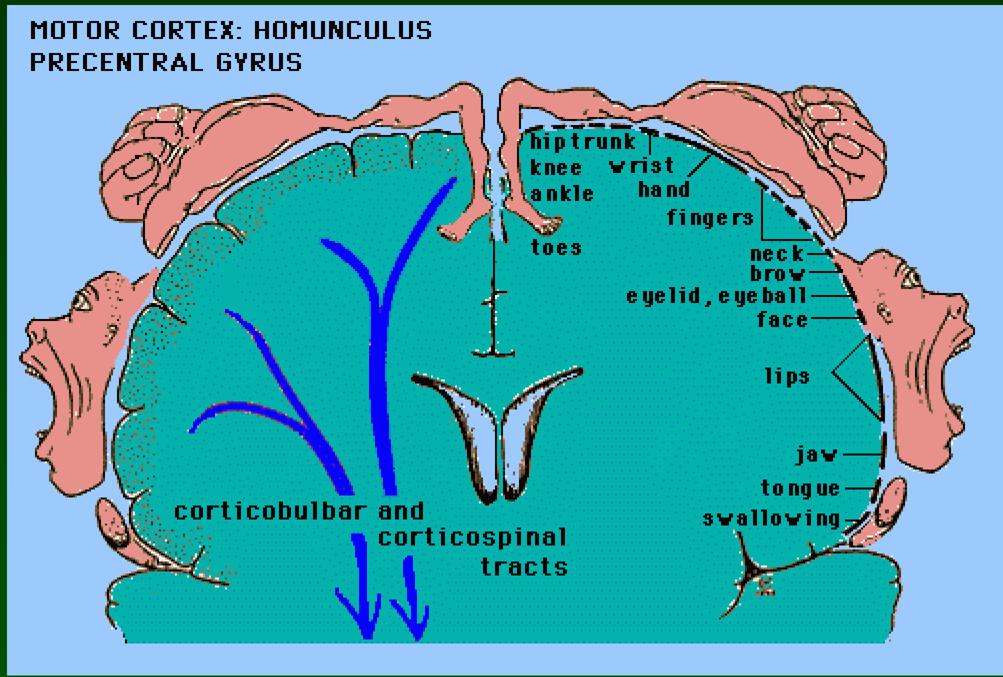
Quantization of perception is useful.

How can it arise?



Motor and somatosensory maps

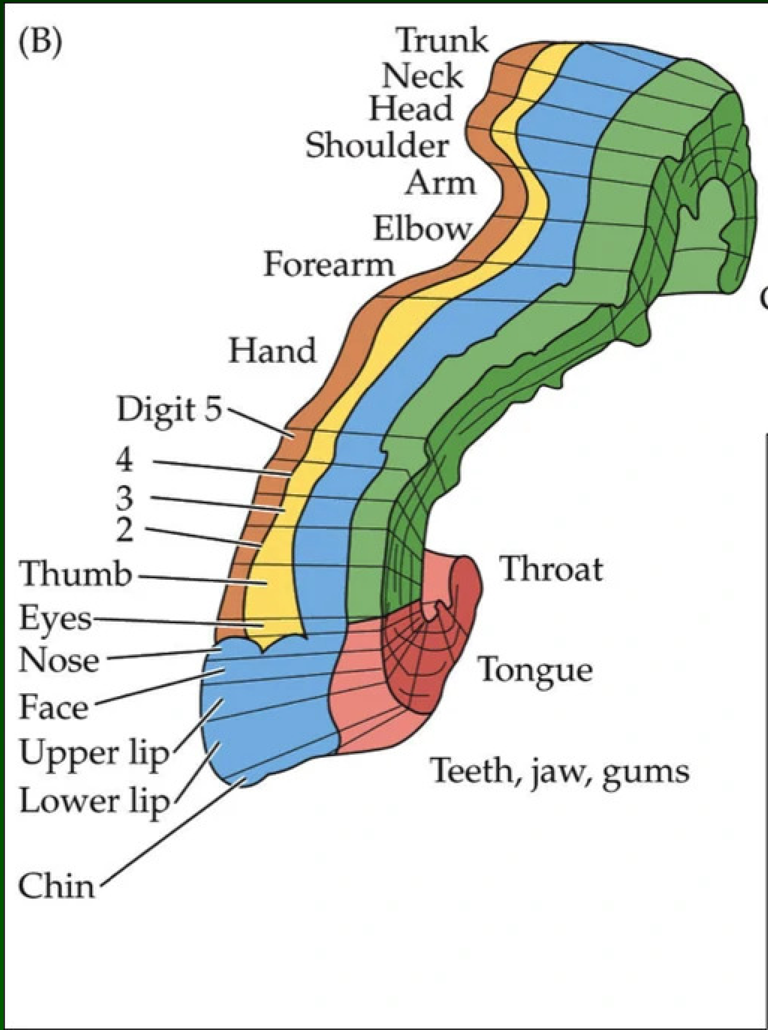


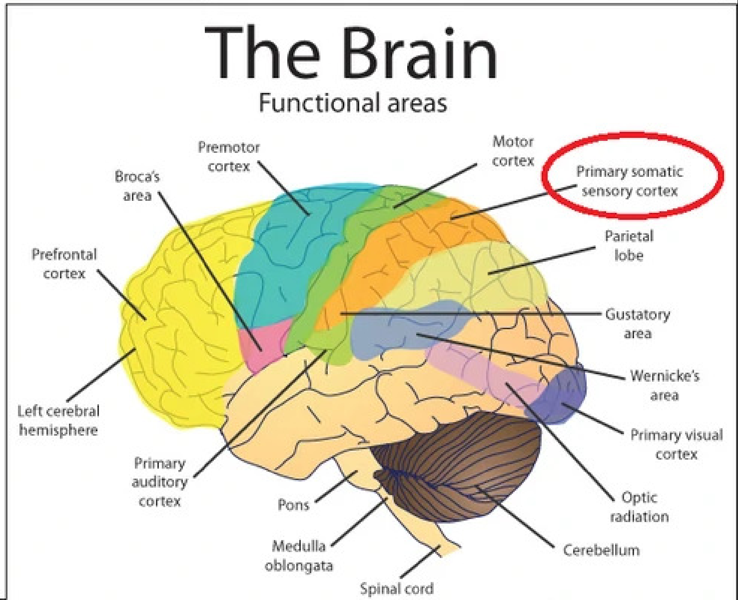


This is a very simplified image, in reality most neurons are multimodal, neurons in the motor cortex react to sensory, aural, and visual impulses (mirror neurons), somatosensory area are in 4 stripes.

Brain has many specialized circuits of perception-action-naming.

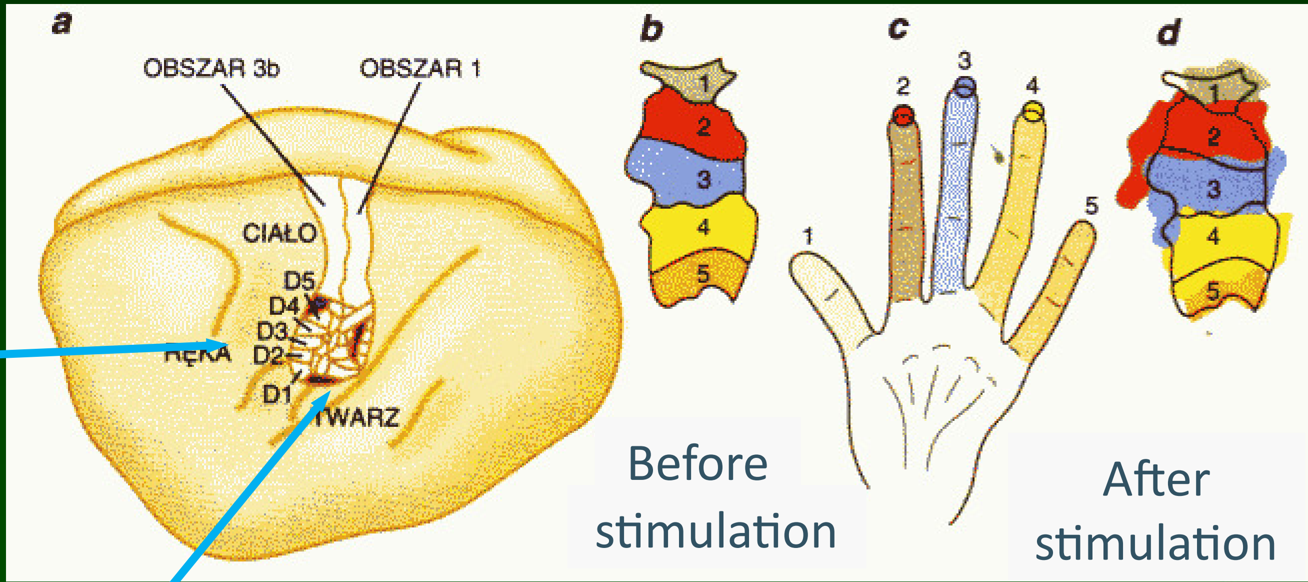
4 somatosensory stripes





Each stripe performs different processing, This gives better resolution at various levels of sensory perception

Finger representation: plasticity



Hand

Face

Sensory fields in the cortex expand after repeated stimulation;
this happens also in the “phantom limb” phenomenon when people feel amputated limbs and other body parts.

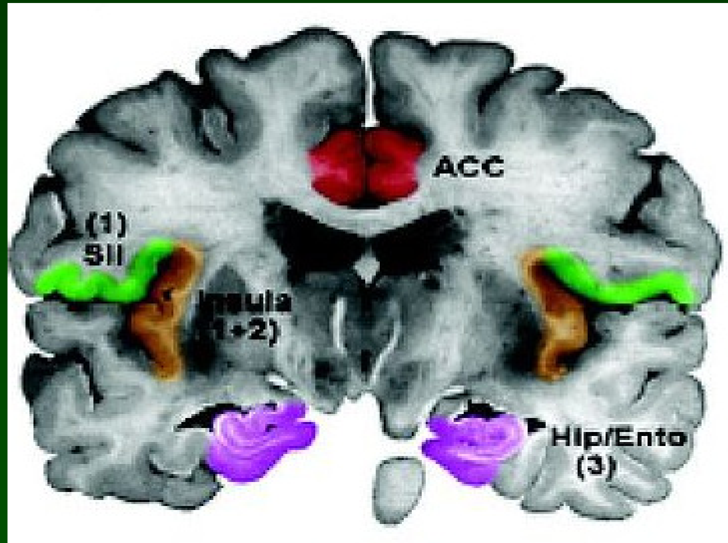
Brains may be overtrained by repeating the same movements (for example typing numbers) and forgetting how to do other movements!

Plasticity of cortical sensory-motor representations is strong.

Secondary sensory cortex

Adjacent to primary sensory cortex lies secondary cortex.

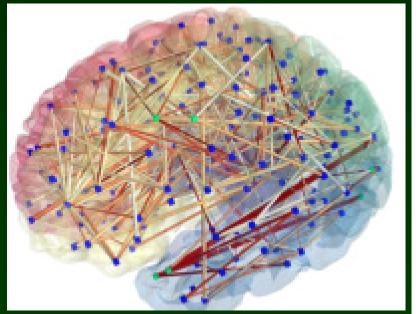
- understand the meaning of stimuli, associate and integrate them with other stimuli and with actions;
- somatosensory SII is close to insula, found only in humans and primates;
- integrates visual, tactile and motor info, enables transfer learning, tactile recognition.



SII lesions may lead to **pain asymbolia**, pain is perceived but not interpreted as suffering. SII tells the brain that pain is unpleasant, hurry to stop it!
It may also lead to a chronic severe pain which may respond to biofeedback.

Visual, acoustic, tactile, olfactory and gustatory stimuli are associated with affective qualities of the experience. Lesions of the secondary sensory cortex leads to selective amnesia which is modality-specific, so this is needed for memory and retrieval of behaviorally salient sensory stimuli.

Tertiary cortices

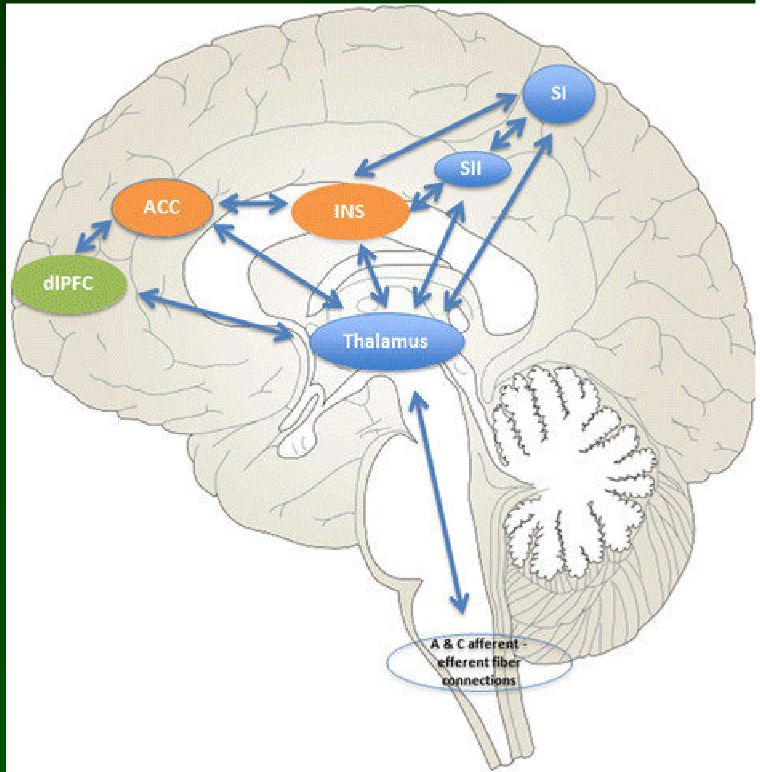


Adjacent to primary and secondary sensory cortex lie association cortices that integrate information on a larger scale, including multi-modal information.

- In auditory cortex: primary reception areas react to basic features of sound like pitch, secondary extract phonemes, tertiary associate phonetic strings with words and their semantics.
- In visual cortex: primary cortex is analyzing edges and other lower level features, secondary cortices shapes, place, movement, colors, while tertiary areas react to various categories of objects and associates them with names.
- In the somatosensory stereognosis (tactile gnosis or haptic perception) requires tertiary cortex to perceive and recognize the form of an object using somatosensory information (texture, size, vibration, spatial properties) and priopriocептive information on hand position. Graphesthesia is the ability to understand what is drawn on your skin.

Pain Matrix

Perception beyond sensori-motor actions involves cognitive appraisal by areas that are in front of the brain and in temporal cortex.



Example: pain matrix.

INS = insular cortex.

ACC = anterior cingulate cortex

dlPFC, dorso-lateral prefrontal cortex,

Blue: recognition of spatial body area and the type of somatic signals: touch, pressure, pain, vibration, temperature.

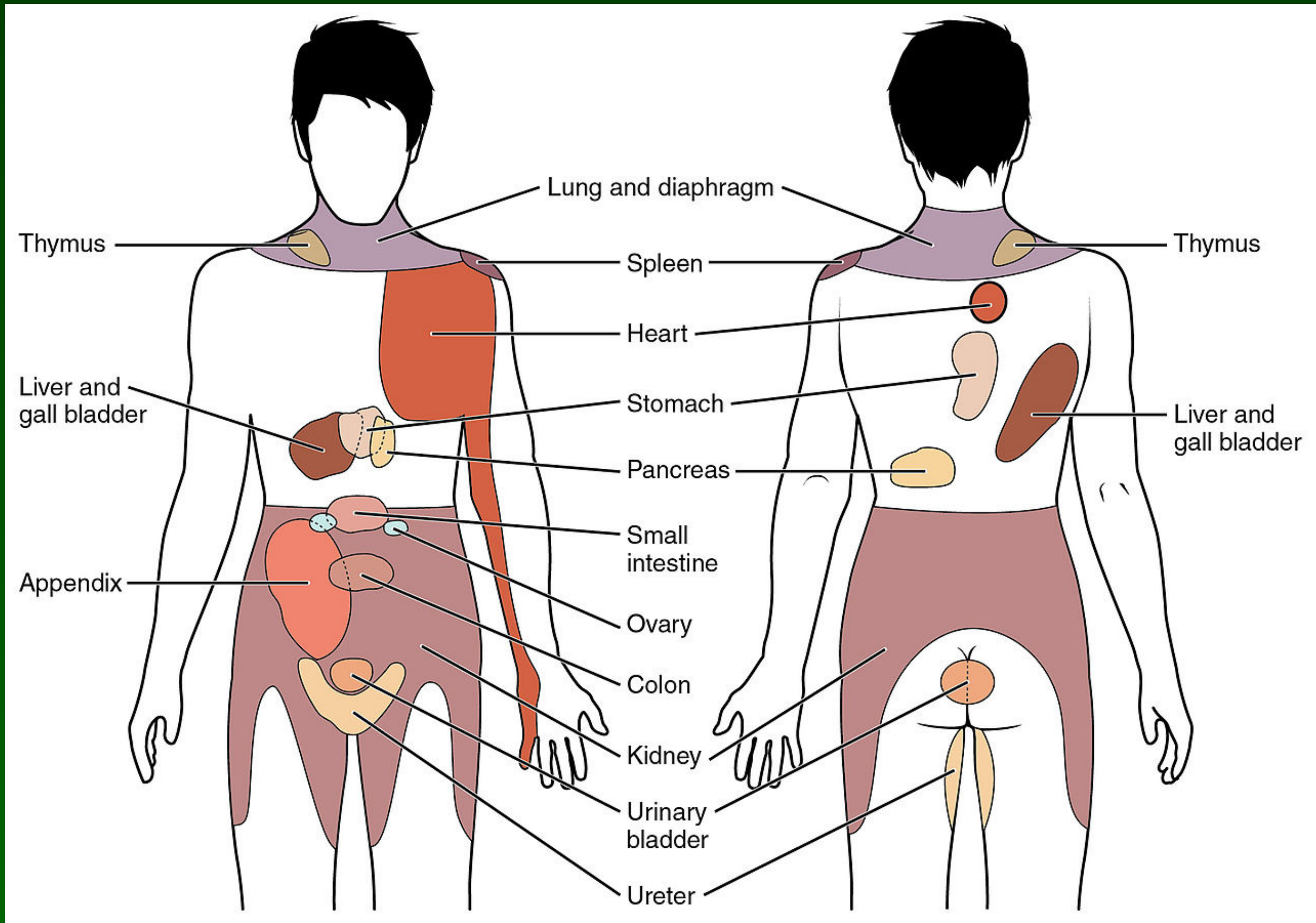
Orange: regions involved in motivation and emotional evaluation (ACC, INS).

These regions are densely connected to many other regions of the brain, including limbic subcortical areas, amygdala, nucleus acumbens, basal ganglia.

Green: dlPFC is involved in cognitive evaluation of the situation and planning of the reaction.

Projected pain

Interoceptive pain: we do not have special nerves from the receptors in our veins, heart or kidneys, in the spine these signals mix with somatic signals. Result: visceral perception maps to various body areas, becomes referred pain.



Tactile agnosia

Agnosia is the inability to process sensory information. It may concern any sensory modality. In case of somatosensory system we have:

Astereognosis Also known as somatosensory agnosia, is the inability to recognize object by touch based on its texture, size and weight. Visually they are recognized and properly named.

Tactile agnosia Impaired ability to recognize or identify objects by touch using one hand alone.

Neurological examination may involve finger gnosis tests, or simultaneous gnosis (recogniton which parts of the body are touched together).

Telling the difference between any of the three middle toes is very difficult without looking.